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THE PRESENT STATUS OF AND PROSPECTS FOR THE DEVELOPMENT OF RADIOELECTRONICS

[Comment: This report consists of a translation from an abridged stenograph of the speech presented at the annual meeting of the Academy of Sciences USSR by Academician A. I. Berg. The stenograph was published in Vestnik Akademii Nauk SSSR (Herald of the Academy of Sciences USSR), No 3, March 1955.]

Radioelectronics -- one of the most interesting, varied, and rapidly developing branches of science -- is drawing more and more attention to itself thanks to the great and often unexpected possibilities which it reveals.

Sometimes our century is called the atomic age. It seems to me that it would be no less correct to call it the age of radioelectronics, since the utilization of atomic energy became possible only with the application of radioelectronic methods in physics. Besides, the fact that radioelectronics plays such an important part in so many sciences justifies such an assertion.

In the spring of 1955, 60 years will have passed since the invention of the radiotelegraph by A. S. Popov. This period can be divided into three parts: the first, the 30 years from 1895 to 1925, in which radiotelegraphy developed essentially by primitive, unproductive methods, is called the radiotelegraphic age.

The second period (1925-1945) should be called the radio engineering age. During this period radiotelegraphy continued to develop, but simultaneously radiotelephony became widely distributed, radio transmitting developed, long distance image transmission was mastered, television appeared, radio navigation became widely used, and radar came into being and achieved many successes.

The transition from simple radiotelegraphy to other fields in which electromagnetic waves are utilized took place mostly thanks to the mastering of electric vacuum techniques and the possibilities of utilizing new radio wave bands -- short, ultrashort, decimeter, centimeter, and millimeter.

For 20 years radio engineering has been developing as an independent engineering science. The radio industry has appeared; engineering methods have been developed for the calculation of radio engineering instruments; radio engineering electronics has been established; and multilateral scientific-research, theoretical, and experimental works have been performed which have provided a solid basis for all branches of radio engineering.

The last 10 year period (1945-1955) can no longer be considered the radio engineering period. It is more to the point to call it the beginning of the radioelectronic epoch, since radioelectronic methods are now in wide use in all branches of science, technology and the national economy.

My speech is dedicated to this last period and to possibilities for the development of radioelectronics in the near future.

However, I will touch upon only a few sides of this all-important theme; and I will dwell on those questions which, it would seem, should interest scientific workers of the most varied branches of knowledge, in particular on questions of radioastronomy, radiospectroscopy, electronic mathematical machines, electronic methods in electroacoustics, radiometeorology, electronic automatics and telemechanics, the application of electronic crystalline semiconductors in science and technology, and new methods of radio engineering. I shall also say a few words on radar, mainly because radar pulse methods and the extremely short radio waves which are used in radar have served as a stimulus for the development of other branches of radioelectronics during the past 10 years.

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Before proceeding to an examination of separate questions I would like to make one general observation.

Fast tempos are characteristic of our times; therefore it is necessary to think, decide, work, and calculate faster than before.

In radioelectronics, a science which is so characteristic of our epoch, we have to deal with extremely rapid processes. Electromagnetic waves travel with a very high velocity -- with the velocity of light -- 300,000 km per/sec. Electromagnetic oscillations are a periodic process with extremely high frequencies. These frequencies are thousands, millions, and billions of times greater than those with which we are familiar. The speeds of motion of electrons which must be dealt with in electronic instruments are extremely high and are measured in figures comparable to the speed of light.

Especially characteristic are the unusually rapid tempos of variation in conditions and the cycle of operation of all radioelectronic apparatus. Therefore, nonstationary processes which develop extremely rapidly in space and time have decisive significance in radioelectronics.

Questions of Theory

The rapid development of socialist industry and the entire national economy has placed many new and variegated practical problems before Soviet science and technology.

The scope and complexity of these problems are, in the majority of cases, so great that their solution in the most economical and effective manner becomes impossible on the basis of only empirical facts and established methods. We need a wide development of the principal theoretical questions which reveal the possibilities for the development of technology. This idea, justified for all branches of knowledge, is especially significant for the future progress of radioelectronics.

The solution of the most important problems of science and technology requires first of all that investigations be developed in the fields of radiowave propagation, pure high-frequency electronics, the theory of antenna-feeder apparatus, and communication (information) theory.

The study of the laws of radiowave propagation remains the most important problem of theoretical radioelectronics. Of importance in this connection is the theoretical and experimental study of the relationships and physical processes taking place in the earth's atmosphere, those taking place in the ionosphere being applicable to long and short waves; those of the troposphere to ultrashort waves.

The recent construction in Colorado, US of a large scientific-research laboratory bears witness to the attention being devoted abroad to the study of radiowave propagation.

A number of works of great significance published in the USSR during the past few years were dedicated to the theory of antenna-feeder apparatus and to related questions of electrodynamics.

At present, a great deal of attention is being paid to problems of the diffraction of electromagnetic waves on metallic closed surfaces of complex form, to the development of the theory of wide-band antenna systems (including thick vibrators of various kinds, wide apertures, etc.), the creation of a

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strict electrodynamic theory of radiation from conical horns and mirrors, the principle of construction of new types of channelization systems for microwaves, and the development of the theory of periodic structures.

Serious progress has been made in the solution of problems of the general theory of communication (information). This theory encompasses two fundamental problems: effectiveness and dependability. The first consists in transmitting the maximum number of communications by the most economical means, i.e., in expending a minimum of power and time and using the smallest possible frequency range. The second problem concerns fidelity in the reception of communications, i.e., in achieving a minimum of distortion from interference. It must be remembered that the requirements of high effectiveness and high dependability are contradictory, and the problem becomes a search for a compromise which can be used in any particular case.

The difficulties connected with the general theory of communications are constantly growing in view of the necessity of transmitting messages over ever-increasing distances under conditions of increasing natural and artificial interference, as well as with greater speed and dependability, and whenever possible with a rigidly limited power output.

In recent years the general theory of communications has been broadly treated in the so-called information theory, which not only generalizes our knowledge and raises it to a higher level but also indicates the means of solving the most difficult problems.

New possibilities have been opened thanks to the utilization of the statistical properties of noise and interference. Much effort is being devoted to the detection and separation of weak signals in the presence of noise.

Electric vacuum devices (tubes) are the most important component part of radio transmitters and receivers. Theoretical work being done in this field will lead to the creation of many new types of electronic tubes. However, problems connected with the motion of electrons in constant and variable electric and magnetic fields in hollow bodies of complex form are far from being solved, as are those concerned with the interaction of electron groups with these fields. These processes are attracting special attention in the microwave range.

In connection with the valuable properties of semiconductor electronic devices and with the ever-increasing scope of their practical application in radioelectronics, it is urgently necessary to continue on a wide front the theoretical works in the study of solid, and in particular crystalline, substances, which we have already been carrying on for some time with great success.

It should be noted that radioelectronics, based on rigid theoretical foundations, is at the same time an experimental science to a considerable degree. The profound development of the theory of nonlinear oscillations by the school of Academicians L. I. Mandel'shtam and N. D. Papaleksi can serve as a good example of the continuous connection between theory and practice. Their remarkable theoretical work in phase and radio interference methods of measuring distances has had wide practical application in the USSR as well as abroad.

## Radar

Radar, or the determination of the location of objects in the air, on water, and on land with the aid of radio waves, came into being a long time ago, but achieved maturity only after the last war. It was widely used in all theaters of military action and continues to be developed at the present time.



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Out of the multitude of different radar methods the radio echo method has become the most widely distributed. In this method distance is measured according to the time it takes a short radio pulse to reach an object and return. This time is measured with great accuracy, and therefore so is the distance. Angular coordinates are obtained by measuring the two angles (in the vertical and horizontal planes) at which the waves reflected from the object return to the receiver antenna. These angles are measured within an accuracy of 1-2$^{o}$.

The ability to operate at any hour of the day and in any conditions of visibility and weather is a valuable property of radar. Usually the range of direct vision is the limit of the range of action, but for high-flying objects this can reach several hundred kilometers.

To get a sharply directed pencil of radio waves, antennas must be used which are rather large in comparison to the wave length being emitted. The use of so-called ultrasort radio waves makes it possible to dispense with unwieldy antennas.

In this way radar stimulated the mastery of pulse techniques and the development of antennas of sharply directional action.

When the properties of pulse radar are mentioned, it is particularly these above properties which are meant. Radar is widely used in military activities; but of much greater value are the technical possibilities which were opened up with the application of radar methods in astronomy, geodesy, spectroscopy, navigation, meteorology, the development of electronic mathematical machines and other fields.

Radiospectroscopy

A new branch of physics, or of radiophysics -- radiospectroscopy -- came into being and was quickly developed in the postwar years on the basis of the technical possibilities opened in the field of radar.

Radio engineering methods (the resonance absorption of radio waves) are here used to investigate a substance in the gaseous, liquid, or solid state. The basic feature distinguishing radiospectroscopy from optical spectroscopy is the use of electronic sources of monochromatic oscillations (in particular klystrons) which assure high resolving power and allow tuning within sufficiently wide limits. At present, electronic oscillators make it possible to conduct investigations in the spectrum of the shortest radio waves: from fractions of a millimeter up to dozens of meters. This provides a band of frequencies lying within the limits of about 8 octaves, whereas in optical spectroscopy a spectrum only one octave in width is used, which means that the required frequencies have to be separated out of a continuous spectrum with the aid of prisms and gratings.

Radiospectroscopic methods of investigation have been applied mainly in physics, chemistry, astronomy, and electronics. Radiospectroscopy is closely connected with theoretical physics, electrodynamics, group theory and quantum mechanics.

Let us consider the basic achievements of this young science.

For the first time in the history of astronomy the discrete spectrum of radio radiation from interstellar space was revealed, in particular the radiation of interstellar hydrogen in our galaxy on a wave length of about 21 cm; this radiation is connected with the transition between levels of the superthin structure of atomic hydrogen.

The discovery of the displacement of the S-level of atomic hydrogen and also the discovery of the anomalous magnetic moment of the electron served as a powerful impetus to the development of quantum electrodynamics; the action of the null oscillations of a vacuum field on elementary particles was studied.

It became possible to maintain a high level of stabilization in superhigh-frequency oscillators with the aid of narrow lines of gas absorption spectra (especially ammonia gas) and to construct on this basis primary standards of frequency (time), which are called molecular clocks.

There is considerable interest in the work of the Physics Institute imeni P. N. Lebedev of the Academy of Sciences USSR in the field of radiospectroscopy, in particular in the creation of new kinds of oscillators and amplifiers with small noise factors with the aid of molecular beams, the so-called molecular oscillators and amplifiers; this makes it possible to obtain extremely accurate standards of time.

The structure of a large number of molecules, which is very important for the development of the theory of chemical combinations and the study of their nature, was investigated.

Radiospectroscopic methods are beginning to be used for the qualitative and quantitative chemical analysis of gas mixtures; some outstanding features of these methods are the rapidity with which analysis can be conducted, the feasibility of maintaining continuous control of the processes, and the fact that only a very small quantity of a substance (a microgram) is needed for the analysis.

In the Kazan' Affiliate of the Academy of Sciences USSR in 1944 Ye. K. Zavoyskiy, now Corresponding Member of the Academy of Sciences USSR, discovered and investigated electronic paramagnetic resonance.

Moments of a large quantity of nuclei were measured, including short-lived radioactive nuclei; the data obtained is extremely important for the development of nuclear theory.

The successes of radiospectroscopy led to the development of methods for generating and multiplying frequencies in the short-wave range, and in this way assured the rapid development of this new branch of radioelectronics. Thanks to the tremendous spatial resolving capability of narrow directional beams of the shortest radio waves, it has become possible to solve direct vision problems with the aid of radio waves.

However, as far as I know, work in the field of radiospectroscopy is being carried out in the USSR on a still insufficient scale.

Radioastronomy

For millenia, astronomers have been observing visible light from the heavenly bodies. The development of astronomy has followed the path of the accumulation of data and the attempt to render it more precise.

In observations of stars the astronomer's greatest enemies are daylight and the earth's atmosphere. It is useless to struggle with daylight and it is therefore necessary to work at night. For the construction of observatories, places are chosen where the atmosphere is more transparent and where the greatest number of quiet and clear nights occurs.

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The atmosphere absorbs a large part of the electromagnetic radiation falling upon it: primary cosmic rays, X-rays, and short ultraviolet rays -- in a word, almost all of the electromagnetic waves which are shorter than the waves of violet color. Almost all of the infrared rays are also absorbed, except those which are nearest to the red line of the spectrum.

Only a narrow slit was formerly at the disposal of the astronomers -- a tiny window to the universe, lying within the frequency limits of the one octave of visible light.

All the valuable data on the physical state, chemical composition, and coordinates of the heavenly bodies were obtained by astronomers by means of rays of visible or near-visible light. Telescopes, refractors, reflectors, and spectrographs were the basic instruments.

Optical astronomy, equipped with very accurate instruments, quietly continued its development and perfected methods of observation up until World War II, and it seemed as if no serious alterations in the approved methods could be expected.

At the beginning of the war a large number of powerful radar stations were set up along the east coast of England. These operated in the meter radio wave band and were intended for the disclosure of German bombers flying over from the east. When the German planes appeared low over the water in the morning hours the radiolocation stations did not pick them up. As was established by lengthy investigations, the reason for this was the exceptionally powerful radio interference emanating from the sun.

Intensive and systematic investigation of the radio radiation from the sun and moon, as well as from interstellar gas, and the so-called radio stars, was begun in the postwar years, even though the first signs of the presence of extraterrestrial radio radiation emanating from the galaxy had been discovered 10 years earlier.

A new era dawned in astronomy -- radioastronomy came into being. It is now one of the most powerful means of studying the universe. Radioastronomy has opened new paths for the solution of many fundamental problems such as the structure of the sun and stars, the composition and distribution of interstellar matter, the origin of cosmic rays, etc.

The earth's atmosphere is transparent not only for the narrow sector of visible light rays. Radio waves from 1 cm to 20 m also reach the earth's surface after passing through the entire atmosphere. Consequently, there are two windows through the atmosphere rather than one: the optical window, one octave wide, and the radio window, which passes about 10 octaves of radio waves. Since radioastronomical observations are possible in any weather as well as day or night (when visual methods of observation are difficult or impossible) their use has opened up wide new horizons.

As has already been said, the sun's radio radiation was first discovered at meter-wave radar stations. Further investigations showed that all the waves used in radar, from centimeter to meter waves, belong to the band for which our atmosphere is almost transparent. Thus radioastronomy received a fine inheritance in apparatus and was able to develop on the basis of the achievements of radar in the field of antennas, sensitive radio receivers, and indicators.

However, because of the weakness of the radio radiation from cosmic formations, radioastronomers had to improve receiver apparatus, and they have been able to receive signals from celestial space hundreds of times weaker than the equipment's own fluctuation noise.

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One of the fundamental objects of radioastronomical observations is the sun. Systematic observation of its radio radiation, conducted in many nations, is constantly being expanded. It has been established that the sun emits all radio waves from a few millimeters up to 15 m, and that the intensity of the radiation varies within wide boundaries, reaching its highest value in periods of maximum solar activity. At these times the radio radiation in meter waves is a thousand times greater than the radiation from a calm sun.

The "radio sun" is not a spherical body, but is rather an ellipsoid of revolution, extended in the equatorial plane. The most intense radiation of meter waves comes from the region of the solar corona, whereas centimeter waves originate mostly in the denser chromosphere.

Systematic investigation of the sun's radio radiation is an effective method of studying the upper layers of the sun's atmosphere. Investigations of the radio radiation of a "disturbed" sun have become especially significant; these investigations are leading to the solution of important problems of the connection between solar and terrestrial phenomena. In particular, we can now predict magnetic storms which arise shortly after the appearance of spots on the sun, as well as strong disturbances in the earth's ionosphere, which interfere to a considerable degree with short-wave radio communications.

Many of the phenomena taking place in the solar atmosphere have been studied in detail by Soviet theoreticians and experimenters. As was theoretically substantiated in 1946, the radio radiation of a calm sun is explained by thermal radiation of the solar atmosphere; the centimeter radiation comes from the chromosphere and the meter radiation from the solar corona. The latter fact was experimentally confirmed for the first time by Soviet scientists during observations of the total solar eclipse in Brazil in 1947 (aboard the ship Griboyedov).

About 10 years ago thermal radio radiation from the moon on a 1.25 cm wave length was discovered. This radio radiation varies but little in the different phases of the moon, despite the fact that the temperature of its surface undergoes great changes depending upon whether it is facing the sun or the earth. Apparently this radio radiation emanates from layers located at a depth up to 50 cm below the surface.

Recently, by investigating the radio radiation of the moon on longer centimeter waves, Soviet scientists established that variations in the intensity of radio radiation on these waves are considerably smaller.

Investigations of the radio radiation from the Galaxy and Metagalaxy occupy a special place in radioastronomy. The discovery during the last 10 years of more than 100 discrete sources of radio radiation which could not be immediately identified with sources of visible radiation, and which were called radio stars, provoked not only great interest, but I might say, a commotion among astronomers.

At the present time, thanks mostly to the works of Soviet physicists and astronomers, it has been learned that the discrete sources of radio radiation are either the remains of explosions (i.e., catastrophes) of supernovae or are connected with the motion of extremely rapid (relativistic) electrons.

It can be considered probable that the general radio radiation from the Galaxy in the meter band is conditioned by rapid electrons, interstellar ionized gas, and, to some degree, discrete sources and separate galaxies. Two colliding galaxies were discovered at the place of one of the powerful sources

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of radio radiation in the constellation Cygnus, which emits radio radiation of greater strength than visible radiation. Methods of investigating radio waves emitted by cosmic objects are in completed conformity with methods used in passive radar.

Of no less interest is the active radiolocation of heavenly bodies -- the moon, planets, meteors -- based on irradiating them with radio waves and registering the reflections received. This new science is called radar astronomy.

It should be remembered that academicians L. I. Mandel'shtam and N. D. Paleksi had already studied the possibilities of radio location of the moon in 1928, and in 1942 had substantiated this problem with technical calculations. Not long ago we learned that in 1943 German scientists registered radio wave reflections from the moon. Practical experiments in this direction were conducted in Hungary and the US in 1946. The distance to the moon measured by the radio echo method agrees closely with values obtained in other ways.

It is theoretically possible to apply radar to the study of large asteroids approaching close to the earth and to the radio location of large planets of the solar system.

Serious scientific results have been achieved in the radio location of meteors and small particles of matter entering the earth's atmosphere. In the highest, most rarefied regions of the atmosphere the surface of meteoric bodies is subjected to intensive bombardment by separate particles of gas; a large part of the energy of these collisions is transformed into heat and, as a result, the matter of the meteor's body evaporates. Atoms fly out with thermal velocities and energies (at a speed of about 40 km/sec relative to the body) from 100 to 1,000 electron volts. In a collision with particles of air the atoms of a meteor's body cause ionization, as a result of which a rapidly diminishing ionized trace follows the meteor, having the form of an extended cylinder or thread, with a diameter of about 20 cm and a length of 10 km or more.

On a clear night up to 10 meteors or "falling stars" can be seen per hour with the unaided eye. This is an insignificant fraction of the number which actually fall to the earth.

The size of meteoric bodies is very small -- a millimeter or a fraction thereof. They usually flare up at altitudes of 120-130 km and are completely evaporated at altitudes of 70-80 km. A large part of the energy of motion of meteoric bodies is transformed into heat and light, and a very small part is expended in ionization. The meteor's trail is easily spotted by radar stations in the meter band.

Thus, in meteor radiolocation the same active method of revealing a reflected body (in this instance a column of ionized gas) is used as in military radar.

The speed with which meteors enter the earth's atmosphere depends upon the relative motion of meteors and the earth. Since the velocity of the earth in its movement around the sun is 30 km/sec, and the heliocentric velocity of meteors reaches 42 km/sec, the geocentric speed of meteoric bodies lies within the limits of 12 and 72 km/sec.

Radiolocation of meteors, which makes it possible to conduct observations around the clock and in any visibility conditions, has considerably aided the study of this interesting phenomenon, since it has fixed a much larger number of meteors than were accessible to visual observation. The heretofore unknown abundant diurnal meteor streams with radiants near the sun were discovered.



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The study of the fine structure of radio echo makes it possible to find the geocentric velocity of meteors; the almost complete absence of hyperbolic velocities of meteoric bodies relative to the sun was established, by which it was shown that they belong to the solar system. The time of existence of a meteor's trace in the atmosphere was measured. For meteoric traces discovered only by radar this time is within tenths of a second, while for those visible to the eye it is considerably longer.

The study of the traces of meteors in the upper layers of the atmosphere has made it possible to begin the systematic investigation of the velocity of the wind, which at high altitudes reaches 100-200 km/hr.

All of this has led to a considerable broadening of our knowledge of the structure and composition of the upper layers of the atmosphere.

Interstellar space, which contains highly rarefied hydrogen, is almost transparent for the visible part of the spectrum in an unexcited state. For this reason optical observations do not give any information about either the concentration of this hydrogen or about its presence in celestial space. Insofar as hydrogen is a source of 21-cm wave radiation, it was possible to obtain by radioastronomical methods extremely valuable information on the concentration of interstellar hydrogen, its distribution in space, motion, etc.

In 1945 the Dutch astrophysicist Van de Holst showed that the transfer between components of the superfine structure of the basic state of the hydrogen atom gives a spectral line with a wave length of about 21 cm. In 1951 the radio lines of hydrogen were discovered independently by observers of three different continents. Thus arose radiospectroscopy of the Galaxy.

At present, the investigation of the radio line of interstellar hydrogen is one of the fundamental methods of studying the interstellar medium. We have been able to determine the kinetic temperature of nonionized hydrogen and to show that interstellar gas is located for the most part in the branches of the spirals of our Galaxy. In 1953 radiation of 21-cm wave length was discovered coming from the Magellanic clouds. At this time the quantity of interstellar hydrogen in these galaxies was estimated, the velocities of turbulent motions were measured, and it was found that both galaxies are dynamically connected.

The methods used in radioastronomy to obtain sufficiently accurate angular coordinates of cosmic sources were borrowed from radar practices, which were in turn taken from optics and acoustics.

To obtain narrow directivity diagrams with receiver antennas, radioastronomical stations use so-called radiotelescopes (i.e., large antennas whose geometric dimensions are many times greater than the wave length being used) in conjunction with sensitive receiver arrangements.

Radiointerferometry is another method of obtaining angular accuracy. Radiointerferometers consist of two or more (up to several dozen) not very large antennas of directional action situated along one line forming a base whose length is anywhere from several dozen to several hundred wave lengths. All the antennas are hooked up to one receiver. Sharp directivity is obtained on account of the interference of coherent oscillations reaching the antennas with various phases depending upon the angle of incidence of the radio waves.

Such a system has a multipetal directivity diagram, so that the width of separate petals can reach several degrees or minutes.

Radiometeorology

Radiometeorology services two fields simultaneously: radio engineering and meteorology. It studies the influence of meteorological factors and processes taking place in the troposphere on the propagation of radio waves. Radio engineering observations also permit the determination of the physical parameters of the troposphere, which are of interest to meteorology.

It is interesting to note that the inventor of the radio, A. S. Popov, was the first in history to use the radio engineering method to detect storms. He used his storm recorder to obtain and record radio waves from storm discharges up to 30 km away. This was the first radio receiver apparatus in the world which received radio waves from a distant source. Thus radiometeorology was actually born 60 years ago.

The influence of meteorological factors makes itself felt in the refraction, dispersion and absorption of radio waves.

A change in temperature and humidity with altitude leads to a change in dielectric permeability, and consequently to the appearance of a refraction coefficient gradient in the vertical plane. The refraction of radio waves usually exceeds to a considerable degree the refraction of visible waves under those conditions and can lead to a significant change (usually an increase) in the range of stations operating on the shortest radio waves.

The dispersion of these waves on particles of water or ice contained in the atmosphere increases sharply with the shortening of the wave, and for centimeter and millimeter waves can lead to a disruption of contact. Reflections from precipitation and clouds give a clear luminous picture of luminosity on the screens of cathode-ray tubes in radar stations. This creates serious inconveniences for observers at radar stations, but can be used to warn fliers of danger.

It was discovered in recent years that dispersion on the heterogeneities of the lower layers of the atmosphere can lead to the stable reception of meter and shorter radio waves far beyond the line of sight. At the present time this phenomenon and its relations to variations in the refraction coefficient of the aerial medium are being studied in detail.

The absorption of the shortest radio waves in water vapor and oxygen is of considerable theoretical and practical interest. The greatest absorption by water vapor takes place at wave lengths of about 1.3 cm. In 1946 thermal radio radiation from the moon was discovered on a wave length close to this (1.25 cm).

A significant absorption of radio waves takes place in raindrops, particles of sleet, and even snowflakes. This limits the possibility of using millimeter radio waves for communication and radar.

Finally, we should note the selective absorption of radio waves on about a 5 mm wave length by the oxygen in the air.

Thus we see that radiometeorology makes it possible to calculate the influence of meteorological factors in the troposphere on the propagation of radio waves; at the same time radio engineering methods aid in studying the formation of clouds and precipitation, as well as heterogeneity and turbulence in the lower layers of the troposphere, all of which has considerable significance for meteorology.

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Radiometeorology makes use of radiohydrometeorological stations, which are automatic installations which measure various hydrometeorological elements without being serviced by personnel: velocity and direction of the wind; pressure, temperature and humidity of the air; atmospheric precipitation; water temperature, etc. These data are encoded and transmitted by radio across considerable distances.

Radiohydrometeorological stations are established in hard-to-reach and sparsely populated regions either on dry land or on floating objects. Their equipment is designed for automatic operation over long periods of time (a year or more). The first radiohydrometeorological stations in the USSR were developed from 1931-1935.

In the 1920's, P. A. Molchanov constructed the first radiosondes at the Slutskaya aerological observatory. A radiosonde is a radiometeorological instrument which measures pressure, temperature, and density of the air and which transmits the values of these meteorological elements at various altitudes when it is raised into the atmosphere. The direction and velocity of the wind at high levels is determined either visually (by an aerological theodolite) or by radio direction finding.

The radioanemometer is also used in radiometeorology; this is an instrument which automatically measures and transmits signals on the velocity and direction of the wind from spaces which are sparsely populated or at a great distance from shore. Near the shore or far out at sea radioanemometers are set up on floating buoys and have automatic transmitting, controlling, and coding apparatus with a clock mechanism. A contact anemometer serves as a wind velocity indicator in a radioanemometer, and a wind cone serves as direction indicator.

Purely radar methods are also used for measuring the direction and velocity of the wind at various altitudes, for observing precipitation and clouds, for detecting temperature and humidity inversions and atmospheric zones of turbulence, and for determining the location of electrical discharges in storms. Observations are conducted of signals which have been reflected from hydrometeors and cloud particles, as well as from sectors of atmospheric electrical heterogeneity (e.g., temperature inversions). When measuring wind velocity and direction, observation is made of a signal which has been reflected from special targets attached to a pilot balloon.

All of these methods of utilizing radio engineering and radar facilities have enriched meteorology and have brought into actual being the things that meteorologists of the past century only dreamed about. Now they have at their disposal more data than they can process. They can be assisted only by electronic calculating machines capable of processing rapidly all of the information coming from meteorological stations.

Ultrasonic Oscillations and Their Application

In the animal kingdom we have at least two examples of the application of pulse phonometry. The South American nocturnal bird, the guacharo, living in dark caverns, emits a sharp cry at a frequency of 7,0000 cps which serves as an audiolocator to determine distances to obstacles.

Bats are able to maneuver in total darkness among wires and other obstacles. It has been established by special experiments that they achieve this by emitting short-duration pulses of very high sounds (ultrasounds). By taking into account the time of the echo's return, they avoid obstacles.

This is the principle upon which are based many technical instruments operating in the ultrasonic band and widely used in industry, physics, and military matters.

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Mechanical vibrations are called ultrasonic if their frequency exceeds 20,000 cycles per second, i.e., if they lie outside the upper limit of the human ear's audibility. At present, it is mechanically possible to obtain ultrasonic vibrations of a much higher frequency, up to one billion cps.

France is the homeland of the study of ultrasonic vibrations and their application. In the solution of the basic problems of ultrasound the achievements of the French academician P. Langevin, a friend of the Soviet Union and a Communist who died in 1946, are especially great. His first successful works in ultrasonics date from 1915-1916.

The first applications of ultrasound were concerned with observations, communications, and signaling aboard submerged submarines. This is explained by the fact that water serves as a good conductor of sound and that on submerged undersea craft it is especially important to use vibrations which will not be received by the human ear.

The action of ultrasonic depth gauges (echo sounder), which are widely used in all navies of the world and have opened up a new era in seafaring and the study of the ocean floor, is based on emission of short directional pulses and measurement of the time between their emission and return. In this way, thanks to an echogram of the ocean floor obtained with the aid of a sounding device, it was possible to locate the sunken ship Luisitania at a depth of 75 m.

Ultrasonic defectoscopes, proposed and developed in 1928 by S. Ya. Sokolov, Member, Academy of Sciences USSR, have application in scientific investigations and production. They make it possible to control the quality of industrial goods with the aid of fast-acting electronic registering instruments.

At present, methods are being worked out for the application of ultrasonic defectoscopes in the quality control of concrete stacks, porcelain insulators, automobile bodies, etc.

The wide introduction into industry of the methods of ultrasonic defectoscopy has favorable economic results, helps to raise the quality of production, and makes it cheaper. There is a declining need for selective control, owing to the decline in the damaging of parts.

Thanks to the use of ultrasonic defectoscopes in many cases accidents were avoided, flaws were detected, and much material was saved.

Impulse methods are used to measure the velocity of motion and absorption of ultrasonic waves in gases, liquids, and solids, and these investigations and measurements can be carried out in a wide range of temperatures, from the very lowest up to the melting points of metals.

The influence of ultrasonic oscillations on a substance is of great interest. Until now there has been no satisfactory general theory of the liquid state, and many questions of the structure of liquids have not been cleared up. Although solid-state theory has been worked out much better than the theory of liquids, even here there are still many unclear questions. The methods of ultrasonic acoustics have opened up prospects for the broadening of our knowledge in the field of liquid and solid-state theory.

The action of ultrasound on a solid or gaseous substance is essentially the agitation of the particles with an ultrasonic frequency. But where liquids are concerned the basic effect is cavitation, which is the formation of discontinuous cavities. When these close up, tremendous pressure is developed (up to 20,000 atm) accompanied by a local increase in the temperature (up to several hundred degrees). Such a method can be used to improve the structure of metals, to settle smoke and dust, to obtain emulsions, to sterilize water and milk, and to degasify liquids, e.g., molten metal and glass.

Ultrasonic soldering and tin-plating of aluminum and stainless steel is used in industry, as well as ultrasonic drilling or, more correctly, chipping of fragile metallic and nonmetallic materials such as borium carbide, tempered steel, glass, and ceramics.

The use of ultrasound for cleaning surfaces, buffing, and polishing is of considerable interest. An object is immersed in a solution or a liquid with particles of an abrasive suspended in it. When the liquid is irradiated with ultrasonic waves the abrasive particles take up a vibratory motion and buff the object.

Ultrasonic oscillations are used successfully in the purification of smokes and exhaust gases. Powerful ultrasonic sirens serve as the oscillation source in this process.

Purification of smokes and gases is especially important for industrial enterprises located in cities. It is of the utmost importance to clean exhaust gases in some chemical plants, for example in sulfuric acid production. Usually up to 10% of the sulfuric acid escapes into the air; a valuable product is lost and the surrounding area is contaminated. After the introduction of purification, practically all the sulfuric acid is extracted from the gas.

Through the ultrasonic influence on several chemical substances it is possible to speed up reactions and control their course, as for example, in the polymerization of high molecular compounds.

Recently biologists have been interested in ultrasonics. Ultrasonic oscillations can be used to produce ferments, vitamins, etc. Since ultrasonic oscillations kill small animals and microorganisms, they can be used for the industrial purification and sterilization of drinking water and food. Vaccines can be obtained by irradiating disease-producing microbes.

In therapy, ultrasound is used to cure diseases of the peripheral nervous system (sciatica, neuralgia); selective heating of tissue is a therapeutic device.

Many examples of the achievements of ultrasonic technology can be mentioned, but this is not my task. I thought it possible to dwell on the properties of ultrasonic oscillations in connection with the fact that radio electronic instruments and methods play an essential part in their use. Radio-electronics in most cases generates high-frequency energy for the excitation of mechanical oscillations in ultrasonic sources and is irreplaceable for the amplification and recording of weak high-frequency oscillations picked up in receivers.

## Electronic Computers

Among the remarkable attainments made possible due to the development of electronics and pulse techniques, electronic computers occupy a special place. The need for speed-up and mechanization of computing work has existed for a long time. Various mechanical and electromechanical arithmetical machines appeared about 100 years ago and exist to this day. Fifty years ago engineers and designers were gladdened by the appearance of the logarithmic slide rule. In 1912 Academician A. N. Krylov designed and built the first mathematical machines in the world for integrating differential equations. This outstanding achievement of Russian science received world-wide acclaim.

The rapid progress in this field achieved in the last decade and continuing to the present is connected with the creation of the electronic computer.



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With the appearance of the first high-speed electronic digital computer (elektronnaya tsyfrovaya bystrodeystvuyushchaya mashina), computing technique entered a new phase. The transition to high speeds, combined with great accuracy, posed the problem of mathematical computations in a new light.

The following two types of problems are mainly solved by means of electronic computers: first, problems involving a huge amount of computational work, requiring as a result the expenditure of much time (by old methods); second, problems requiring a very high speed of solution, which was unattainable by former computing devices.

Problems of the first type are related mainly to contemporary problems of aerodynamics, meteorology, and nuclear physics. These problems are solved by means of large universal electronic digital computers (tsifrovaya schetnaya mashina).

Problems of the second type are related to problems of control of complex and automatized technological and industrial processes requiring an exact maintenance of operating conditions. These problems are solved by specialized or control machines.

Automatic electronic high-speed digital computers can assure accuracy to millionths of a percent; their operating speed provides several thousand operations per second with 10-figure numbers.

Such machines are used with great success for the solution of mathematical problems and problems of physics, applied mathematics, mechanics, chemistry, statistics, and astronomy. They provide substantial aid to radio physicists in solving questions on the theory of electromagnetic oscillations, wave equations of the propagation of radio waves in free space and in restricted media, and problems of nonlinear mechanics encountered in the theory of electrical and mechanical oscillations. Problems of stability and automatic regulation can be solved much more quickly and accurately with the aid of electronic digital computers (elektronnaya matematicheskaya mashina diskretnogo scheta). Many problems of magnetism, distribution of heat, aerodynamics, and hydrodynamics in general cannot be solved without use of present-day electronic digital computers (elektronnaya mashina diskretnogo scheta).

The speed with which specialized machines solve problems permits their use where high-speed reaction to regulated processes is required; they are used successfully in harmonic analysis and also for solving problems in linear algebra, the statistical processing of experimental results, differentiation, interpolation, numerical integration, solving of systems of algebraic equations, summation and multiplication of series, calculation of matrixes and determinants, etc.

Naturally, the realization of all these possibilities, in large measure determining the tempo of the development of contemporary science, is accomplished by complex means. The large present-day electronic computer contains hundreds and thousands of miniature and long-lasting vacuum tubes, electronic crystal amplifiers and rectifiers, resistors and condensers, cathode-ray storage tubes, mercury or quartz delay lines, and other units. All these units are combined into a single complex mechanism occupying a rather large space.

The electronic computer is supposed to complete in rigid sequence and completely reliably, practically without inertia, a huge number of the simplest operations for transmittal of data from one part of the machine to another and to give out in a short time the final result of its work in a form suitable for use.



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One of the most important and most responsible operations -- the development of the program -- has to be performed by mathematicians. Using methods of approximate computations, they make up a series of sequential commands serving as a program or assignment for the operation of the machine. After the program has been introduced into the machine, the computations are done automatically.

Programming requires much time, as well as personnel with special training and high qualifications. Specialists of a definite type are necessary for high-grade and relatively rapid programming. One should bear in mind that the operation of the machine depends in large measure on the quality of the program, inasmuch as the machine's role in the end is reduced to processing the assignment (program), whatever it be, and to giving out the results. The machine cannot correct an error in the program, and the quality and tempo of its work to a large extent are dependent on the degree to which the program corresponds to the posed problem.

In order to speed up the operation of the machines it is necessary to strive for automatic programming. This will be a further step in the automation of the operation of computers.

In addition to digital machines (mashina diskretnogo scheta), analog machines (mashina nepreryvnogo deystviya), or electrical modeling machines, are widely used for less precise computations, and chiefly for qualitative evaluation of engineering calculations and research.

Finally, the urgent need for development of scientific-reference and statistical machines should be noted.

The most immediate prospects for development of electronic computers lie in increasing the reliability of their operation by means of widespread use of electronic semiconductor devices (instead of tubes), cold-cathode thyratrons, ferromagnetic and ferroelectric elements, and new memory elements (in particular on the basis of barium titanate crystals); in the creation of small high-speed electronic digital machines for widespread use in science, engineering, and agriculture; in the automation of programming and program inspection; in the development of specialized high-speed electronic digital computers suitable for power systems, electric stations, chemical processes, the metallurgical and printing industry, and navigation problems.

In the next few years widespread introduction of small electronic computers in practice can be expected. These machines will be considerably smaller and cheaper, but not less reliable, than the large ones. They will find use in scientific-research institutes, design bureaus, industrial enterprises, and educational institutions.

It must be said that certain fields of physics and meteorology, in particular weather forecasting, generally cannot develop without radically changing their technical equipment.

The introduction of scientific-reference and statistical machines into a practical information service is quite important. The development of science and the growing need for timely accounting of attainments in the field being exploited or in neighboring fields require widespread utilization of high-speed scientific-reference machines for the classification and accounting of the content of the continually growing world fund of scientific literature. The solution of this problem will lead to a considerable increase in the productivity of the work of scientific workers, and will aid in the quick utilization of the results of previous investigations, observations, and technical developments.

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A feature of scientific-reference and statistical machines is the use of very capacious storage devices with long "memories" which reproduce a record with great speed, and also the use of high-speed logical elements which permit the simultaneous processing of material according to a large number of given symbols.

The president of the Academy of Sciences of the USSR, A. N. Nesmeyanov, has repeatedly pointed out the importance of solving this problem.

The work of Soviet scientists, engineers, designers, and technologists in the field of increasing the productivity of intellectual work, and with the aim of smoothing the contradictions between intellectual and physical work, is directed towards the creation and widespread utilization of electronic computers. This work is receiving much attention and support in our country and is developing rapidly.

## Electric Vacuum Instruments

The progress of contemporary physics has led to the creation of two new technical branches: nuclear technology and superhigh-frequency radio electronics. The latter is based on the study of electron streams (in vacuo and in gases). The remarkable properties of these streams, which stipulate the extreme variety of electric vacuum instruments and their wide application, can be characterized as follows.

The velocity of motion of the electron streams, varying within tremendous limits (reaching almost the speed of light), makes it possible to create fast-acting noninertial instruments, which is very important for the automation of all kinds of processes, and to generate electromagnetic oscillations with wavelengths of 1-2 mm or with frequencies up to $3 \times 10^{11}$ oscillations/sec.

The energy concentration of electron streams makes it possible to generate short duration powers of tens of thousands of kilowatts or long duration powers of hundreds of thousands of kilowatts.

The energy of electron streams also has the ability to be broken down into very small values, measured in billionths of a milliwatt.

All of these properties result in the solution of many problems with the aid of electronic instruments which could not be solved by any mechanical means.

Electric vacuum instruments are the fundamental elements of any radio electronic apparatus, and they determine its basic characteristics.

At the present time industry is producing hundreds of types of electric vacuum instruments of varied technical characteristics and construction. The most important ones are superhigh-frequency instruments to generate, amplify, and use centimeter and millimeter wave energy. Some of them (e.g., linear accelerators) are several meters in height and require special mountings.

Progress of nuclear science without such instruments is unthinkable, and without them we cannot maintain our country's defense.

We must not think that electronics has already completed its development. It is in the stormiest period of its growth, research is developing, and new electric vacuum instruments are being developed which will aid in the creation of tomorrow's technology. Physicists must help the workers of industry solve problems connected with the generation of powerful electron beams, their focusing and direction, and their interaction with electromagnetic waves.

## Semiconductor Electronic Devices

During the entire period of radio's existence established views and methods of operation have changed fundamentally more than once. Forty years ago, with the appearance of electronic tubes, there began the development of a number of new branches of radio engineering -- short waves, radiotelephony, radio navigation, etc.

In the 1920's our countryman O. V. Losev invented and successfully used radio receiver circuits with crystal amplifiers and heterodyne. His work attracted the attention of scientists, engineers and radio amateurs in every country of the world. For several years Losev's name did not leave the pages of foreign journals, but later it began to appear less and less often, and by 1930 Losev's crystal amplifier and heterodyne were long forgotten.

In the 1930's mostly in Germany, interest was again drawn to electronic crystals, especially silicon and germanium. But these works were also quickly abandoned.

Five years ago a new epoch in radio engineering began: a rival of vacuum electronic instruments appeared in the form of solid crystal electronic amplifiers and generators.

In connection with the necessity of developing the reception and detection of centimeter radio waves for radar purposes, silicon detectors were created at the beginning of World War II and found wide application. Crystal amplifiers and oscillators, created on a more highly perfected technological base than had been possible in Losev's time, were developed along this idea after the war.

These small devices are now causing another revolution in radio engineering. We already have radio receivers and television sets without vacuum tubes (except cathode-ray tubes); they have been replaced by miniature solid electronic amplifiers which have great advantages: longevity, insignificant power requirements, mechanical strength, and small size. Before our eyes these crystals are replacing electronic tubes, first in low-frequency circuits, and then gradually reaching the higher radio frequencies as well. They are being very widely applied in complex circuits of telephone stations, in mathematical machines, and in many automatic devices.

For some time it seemed that their nonuniformity of parameters and limited operating temperatures would present an insurmountable deficiency of crystal devices. But the development of a more highly perfected technology, the transition to monocrystals, and the utilization of special alloys have averted these dangers. Now there can be no doubt that, thanks to the appearance of industrial types of electronic crystals, radio engineering methods will become a firm part of many branches of technology, where until now they could not be used because of the short life and lack of dependability of electronic tubes.

Naturally, the appearance of crystal electronic devices capable of dependable operation for tens of thousands of hours is attracting general attention. These devices have a great future.

## Questions in the Production of Radio Apparatus and Radio Components

In the construction and production of contemporary radio apparatus, especially that which is intended for wide use, considerable attention is devoted to the technology which will guarantee high quality, long and dependable



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operation under various operating conditions, and economical as well as rapid construction. Mechanization and automation of the fundamental operations of production and quality control of the radio apparatus being produced are of essential significance in this regard. A significant effect is achieved by automatized and mechanized production of units and their subsequent assembly in blocks, printed circuits, etc.

The component parts of a radio apparatus (resistors, capacitors, transformers, switches, etc.) have a fundamental influence on its quality and methods of production. Sometimes several tens of thousands of various kinds of components are used in present-day complex radio apparatus. Consequently, for the normal operation of contemporary radio apparatus, components are needed which not only have good initial characteristics but also very high operational dependability and stability.

In many cases, minimal dimensions and the possibility of lengthy operation in high ambient temperatures are required of contemporary radio components. The increasingly widespread use of semiconductor devices and the technology of printed circuits required the creation of superminiature parts.

Every year hundreds of millions of the most varied kinds of radio components are produced. Wide mechanization and automation of their production assumes fundamental significance in this regard. Our industry has a lot to do in this field, and the aid of the Institute of Automatics and Telemechanics, Academy of Sciences USSR, would be very useful.

It is impossible to make radio components answering current requirements without high quality organic, inorganic, and magnetic materials. In recent years Soviet scientists and specialists have created many kinds of synthetic plastics, compounds, and varnishes having high electrical indexes with high moisture and heat stability. The synthesis of a heat-resistant dielectric for capacitors, achieved by the Institute of High-Molecular Compounds, Academy of Sciences USSR, was a great feat. Important successes have been achieved in the fields of radioceramics, ferroelectrics, magnetic materials, magnetic dielectrics, and ferrites.

We should note that the radio component and materials industry is experiencing an acute lack of scientific facilities. We must attract academic institutes and higher educational institutions to the solution of problems which are important for the future development of radio engineering.

## Radioelectronics and Questions of Automation

Contemporary automatics and telemechanics is based to a considerable degree on the achievements of radioelectronics. In particular, we should note the wide application of photocells and thermal elements, infrared and ultraviolet absorption, radiospectroscopy, ultrasonics, and other physical phenomena and instruments.

The transition from electronic circuits containing tubes to schemes constructed with semiconductor, magnetic, ferroresonance and ferroelectric elements has enabled us to increase the dependability of systems and in many cases to reduce dimensions and power consumption.

Electronic-ionic devices (especially thyratrons) are widely used for the direction of automated gear drives.

The use of calculating devices has increased the speed and accuracy of regulation, recording, and processing of the data from measuring and recording instruments and has aided in the development of automatic control systems which give selective information (i.e., only from those sectors of production where there are departures from the given conditions).

The successful solution of the practical problems of automatics and telemechanics can be achieved only as a result of the creation of the most dependable and simplest apparatus. For this we must introduce advanced technology for the production of radio engineering instruments, components, and materials. It is precisely for this reason that the general technical level of the development of automatics and telemechanics is determined by the development of the radio engineering industry and in turn determines the latter's future progress.

The solution of important scientific-technical problems, most of which are connected with the general state of radio electronics, must precede the wide utilization of automatics and telemechanics.

Among the scientific problems whose solution will aid the development of automatics and telemechanics are: the creation of a general theory of telemechanical devices based on the development of information and feed-back theories; a theory of relay systems and a general theory of transformations; a general theory of dependability and interference rejection of telemechanized and automatic systems; and the development of rational methods for utilizing communication channels for telemechanized systems.

Complex automation requires continuous accounting for the influence exerted on production processes by various randomly changing parameters which are part of a complicated functional interdependence, as well as the rendering of immediate accounts of the actions of many complex rapid processes, which cannot be realized without the use of small, fast-acting automatic electronic computers.

The efforts of Soviet scientists must be directed toward the quickest possible solution of these problems.

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